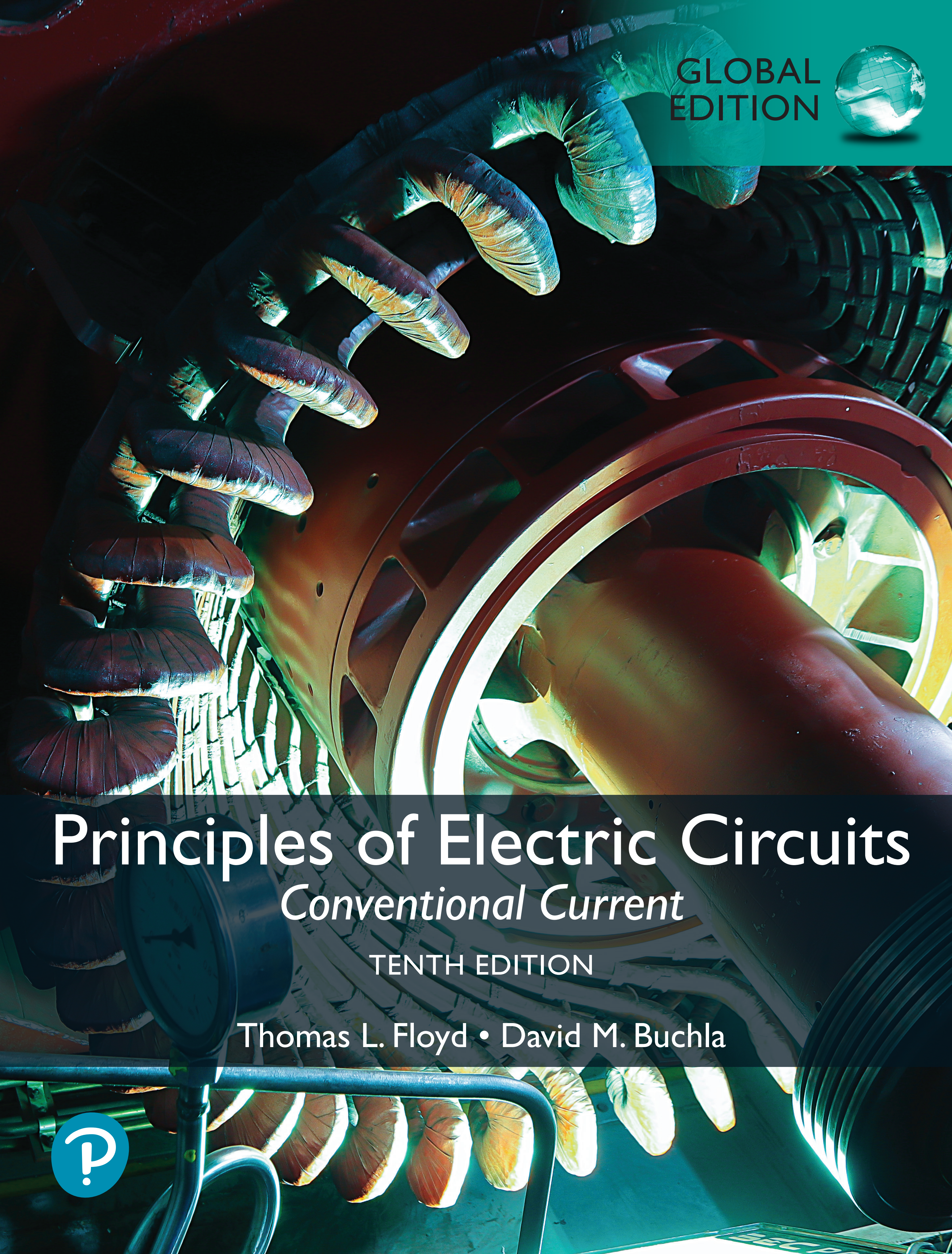


GLOBAL EDITION

Principles of Electric Circuits

Conventional Current

TENTH EDITION

Thomas L. Floyd • David M. Buchla

Principles of Electric Circuits

Conventional Current

Tenth Edition
Global Edition

Thomas L. Floyd

David M. Buchla

Loading of the Voltage Source

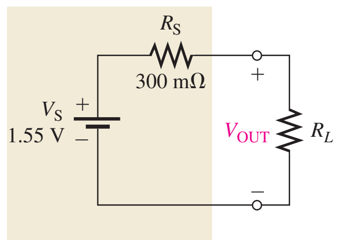
When a load resistor is connected across the output terminals, as shown in Figure 8–2(b), all of the source voltage does not appear across R_L. Some of the voltage is dropped across R_S because R_S and R_L are in series. Current in R_S also causes internal heating of the source. In the case of high currents, internal heating can be significant.

If R_S is very small compared to R_L, the source approaches ideal because almost all of the source voltage, V_S, appears across the larger resistance, R_L. Very little voltage is dropped across the internal resistance, R_S. If R_L changes, most of the source voltage remains across the output as long as R_L is much larger than R_S. As a result, very little change occurs in the output voltage. The larger R_L is, compared to R_S, the less change there is in the output voltage. Example 8–1 illustrates the effect of changes in R_L on the output voltage when R_L is much greater than R_S.

EXAMPLE 8–1

A certain C cell battery has an output voltage of 1.55 V and an internal resistance of 300 mΩ as shown in Figure 8–3. Calculate the output voltage for loads of 5.0 Ω, 10 Ω, and 100 Ω.

► FIGURE 8–3



Solution For $R_L = 5.0\ \Omega$, the voltage output is

$$V_{OUT} = \left(\frac{R_L}{R_S + R_L}\right)V_S = \left(\frac{5.0\ \Omega}{5.3\ \Omega}\right)1.55\text{ V} = \mathbf{1.46\ V}$$

For $R_L = 10\ \Omega$,

$$V_{OUT} = \left(\frac{10\ \Omega}{10.3\ \Omega}\right)1.55\text{ V} = \mathbf{1.50\ V}$$

For $R_L = 100\ \Omega$,

$$V_{OUT} = \left(\frac{100\ \Omega}{100.3\ \Omega}\right)1.55\text{ V} = \mathbf{1.55\ V}$$

Notice that the output voltage is within 10% of the source voltage, V_S, for all three values of R_L because R_L is at least 10 times R_S.

*Related Problem** Determine V_{OUT} for the cell in Figure 8–3 if the internal resistance is 150 mΩ and $R_L = 5.0\ \Omega$.

MultiSim

Use Multisim file E08-01 to verify the calculated results in this example and to confirm your calculation for the related problem.

*Answers are at the end of the chapter.

The output voltage decreases significantly as the load resistance is made smaller compared to the internal source resistance as illustrated in the previous example for a single cell. This is true for electronic power supplies but the source resistance in a well regulated supply is much less than 1 Ω. In the case of batteries, the output voltage drops and the cell resistance increases as the battery ages.

Determining the Internal Resistance of a Voltage Source

The internal resistance of a voltage source cannot be measured directly but can be calculated from indirect measurements. To determine the internal resistance, start by measuring the no load output voltage, V_{NL}. Place a known load resistor, R_L, across the output. (R_L should not be so small that the load current exceeds the current limit for the source.) Measure the voltage under load V_{L}. The difference between V_{NL} and V_{L} is the drop across the source resistance, V_{RS}. That is:

$$V_{\text{RS}} = V_{\text{NL}} - V_{\text{L}}$$

The current in the source resistance is the same as load current:

$$I_{\text{RS}} = \frac{V_{\text{L}}}{R_L}$$

The source resistance can now be calculated by substituting and applying Ohm's law:

$$R_{\text{S}} = \frac{V_{\text{RS}}}{I_{\text{RS}}} = \frac{V_{\text{NL}} - V_{\text{L}}}{\dfrac{V_{\text{L}}}{R_L}} = R_L\left(\frac{V_{\text{NL}} - V_{\text{L}}}{V_{\text{L}}}\right).$$

EXAMPLE 8–2

A regulated power supply has a no-load output voltage of 5.00 V that drops to 4.98 V when a 5.10 Ω resistor is connected across the output. What is the internal resistance of the source?

Solution

$$R_{\text{S}} = R_L\left(\frac{V_{\text{NL}} - V_{\text{L}}}{V_{\text{L}}}\right)$$

$$= 5.10\,\Omega\left(\frac{5.00\text{ V} - 4.98\text{ V}}{4.98}\right) = \mathbf{20.5\ m\Omega}$$

Related Problem Calculate the internal resistance of a D cell with the same load if the no-load voltage is 1.55 V and the loaded voltage is 1.45 V.

SECTION 8–1 CHECKUP
Answers are at the end of the chapter.

1. What is the symbol for the ideal voltage source?
2. Draw a practical voltage source.
3. What is the internal resistance of the ideal voltage source?
4. What effect does the load have on the output voltage of the practical voltage source?
5. Why can't the internal resistance of a voltage source be measured by an ohmmeter?

8–2 The Current Source

As you learned in Chapter 2, the current source is another type of energy source that ideally provides a constant current to a variable load. The concept of the current source is important in certain types of transistor circuits.

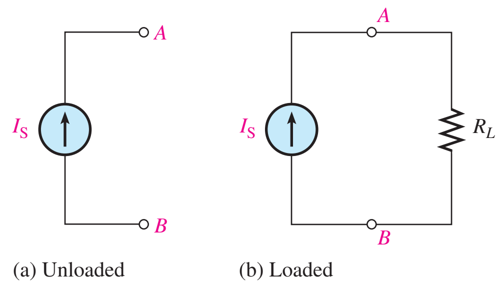
After completing this section, you should be able to

- **Describe the characteristics of a current source**
  - Compare a practical current source to an ideal source
  - Discuss the effect of loading on a practical current source

Figure 8–4(a) shows a symbol for the ideal current source. The arrow indicates the direction of source current, I_S. An ideal current source produces a constant value of current through a load, regardless of the value of the load. This concept is illustrated in Figure 8–4(b), where a load resistor is connected to the current source between terminals A and B. The ideal current source has an infinitely large internal parallel resistance.

FIGURE 8–4

Ideal current source.

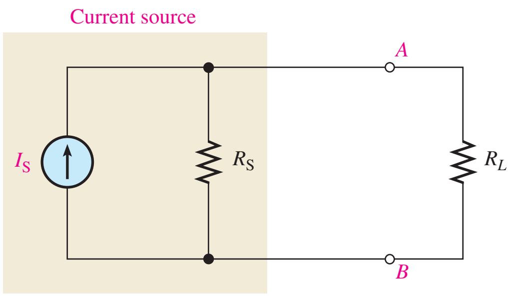


Transistors act basically as current sources, and for this reason, knowledge of the current source concept is important. You will find that the equivalent model of a transistor does contain a current source.

Although the ideal current source can be used in most analysis work, no actual device is ideal. A practical current source representation is shown in Figure 8–5. Here the internal resistance appears in parallel with the ideal current source.

FIGURE 8–5

Practical current source with load.



If the internal source resistance, R_S, is much larger than a load resistor, the practical source approaches ideal. The reason is illustrated in the practical current source shown in Figure 8–5. Part of the current, I_S, is through R_S, and part is through R_L. The internal source resistance, R_S, and the load resistor, R_L, act as a current divider. If R_S is much larger than R_L, most of the current is through R_L and very little through R_S.

As long as R_L remains much smaller than R_S, the current through R_L will stay almost constant, no matter how much R_L changes.

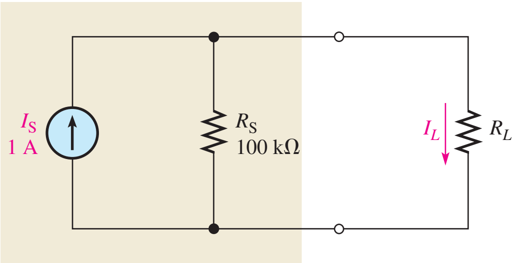
If there is a constant-current source, you can normally assume that R_S is so much larger than the load resistance that R_S can be neglected. This simplifies the source to ideal, making the analysis easier.

Example 8–3 illustrates the effect of changes in R_L on the load current when R_L is much smaller than R_S. Generally, R_L should be at least 10 times smaller than R_S ($10R_L \leq R_S$) for a source to act as a reasonable current source.

EXAMPLE 8–3

Calculate the load current (I_L) in Figure 8–6 for the following values of R_L: 1 kΩ, 5.6 kΩ, and 10 kΩ.

▶ FIGURE 8–6



Solution For $R_L = 1\ \text{k}\Omega$, the load current is

$$I_L = \left(\frac{R_S}{R_S + R_L}\right)I_S = \left(\frac{100\ \text{k}\Omega}{101\ \text{k}\Omega}\right)1\ \text{A} = \mathbf{990\ mA}$$

For $R_L = 5.6\ \text{k}\Omega$,

$$I_L = \left(\frac{100\ \text{k}\Omega}{105.6\ \text{k}\Omega}\right)1\ \text{A} = \mathbf{947\ mA}$$

For $R_L = 10\ \text{k}\Omega$,

$$I_L = \left(\frac{100\ \text{k}\Omega}{110\ \text{k}\Omega}\right)1\ \text{A} = \mathbf{909\ mA}$$

Notice that the load current, I_L, is within 10% of the source current for each value of R_L because R_L is at least 10 times smaller than R_S in each case.

Related Problem At what value of R_L in Figure 8–6 will the load current equal 750 mA?

SECTION 8–2 CHECKUP

1. What is the symbol for an ideal current source?
2. Draw the practical current source.
3. What is the internal resistance of the ideal current source?
4. What effect does the load have on the load current of the practical current source?

8–3 SOURCE CONVERSIONS

In circuit analysis, it is sometimes useful to convert a voltage source to an equivalent current source, or vice versa.

After completing this section, you should be able to

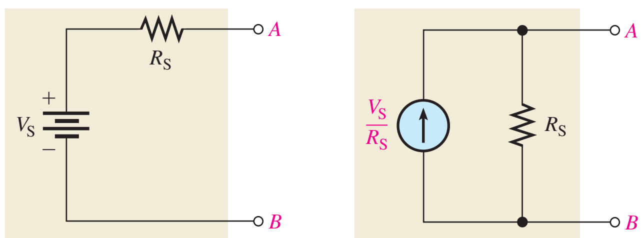
- **Perform source conversions**
  - Convert a voltage source to a current source
  - Convert a current source to a voltage source
  - Define *terminal equivalency*

Converting a Voltage Source to a Current Source

The source voltage, V_S, divided by the internal source resistance, R_S, gives the value of the equivalent current source.

$$I_S = \frac{V_S}{R_S}$$

The value of R_S is the same for both the voltage and current sources. As illustrated in Figure 8–7, the directional arrow for the current points from minus to plus. The equivalent current source is in parallel with R_S. Notice that the equivalent current source is the same as the current in a shorted load.



(a) Voltage source (b) Current source

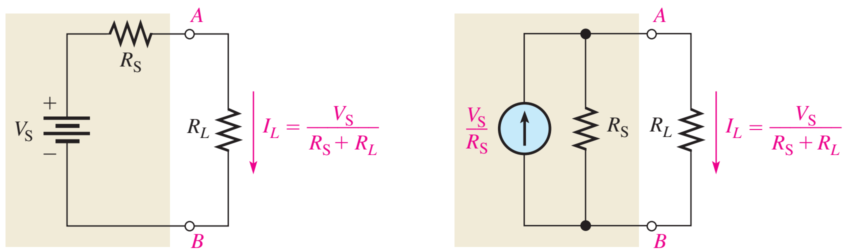
▲ FIGURE 8–7

Conversion of voltage source to equivalent current source.

Equivalency of two sources means that for any given load resistance connected to the two sources, the same load voltage and load current are produced by both sources. This concept is called **terminal equivalency**.

You can show that the voltage source and the current source in Figure 8–7 are equivalent by connecting a load resistor to each, as shown in Figure 8–8, and then calculating the load current. For the voltage source, the load current is

$$I_L = \frac{V_S}{R_S + R_L}$$



(a) Loaded voltage source

(b) Loaded current source

▲ **FIGURE 8–8**

Equivalent sources with loads.

For the current source,

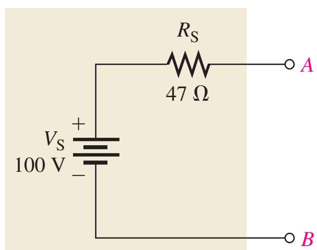
$$I_L = \left(\frac{R_S}{R_S + R_L}\right)\frac{V_S}{R_S} = \frac{V_S}{R_S + R_L}$$

As you see, both expressions for I_L are the same. These equations show that the sources are equivalent as far as the load or terminals A and B are concerned.

EXAMPLE 8–4

Convert the voltage source in Figure 8–9 to an equivalent current source and show the equivalent circuit.

► **FIGURE 8–9**

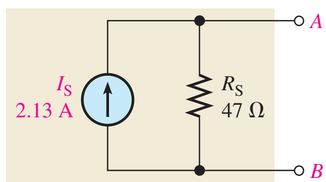


Solution The value of the internal resistance, R_S, of the equivalent current is the same as the internal resistance of the voltage source. Therefore, the equivalent current source is

$$I_S = \frac{V_S}{R_S} = \frac{100\text{ V}}{47\ \Omega} = 2.13\text{ A}$$

Figure 8–10 shows the equivalent circuit.

► **FIGURE 8–10**



Related Problem Determine I_S and R_S of a current source equivalent to a voltage source with $V_S = 12$ V and $R_S = 10\ \Omega$.